

The Diagnostic Utility of Computer-Assisted Auscultation for the Early Detection of Cardiac Murmurs of Structural Origin in the Periodic Health Evaluation

Pierre L. Viviers, MBChB, MMedSc, MSc (Sports Med), FACSM,^{*†‡§}

Jo-Anne H. Kirby, MBChB, MSc (Sports Med),^{†‡§} Jeandré T. Viljoen, BSc (Physio), MPhil (Exercise Sc),^{†‡§} and Wayne Derman, MBChB, BSc (Med) (Hon), PhD, FFIMS^{†§}

Background: Identification of the nature of cardiac murmurs during the periodic health evaluation (PHE) of athletes is challenging due to the difficulty in distinguishing between murmurs of physiological or structural origin. Previously, computer-assisted auscultation (CAA) has shown promise to support appropriate referrals in the nonathlete pediatric population.

Hypothesis: CAA has the ability to accurately detect cardiac murmurs of structural origin during a PHE in collegiate athletes.

Study Design: Cross-sectional, descriptive study.

Level of Evidence: Level 3.

Methods: A total of 131 collegiate athletes (104 men, 28 women; mean age, 20 ± 2 years) completed a sports physician (SP)-driven PHE consisting of a cardiac history questionnaire and a physical examination. An independent CAA assessment was performed by a technician who was blinded to the SP findings. Athletes with suspected structural murmurs or other clinical reasons for concern were referred to a cardiologist for confirmatory echocardiography (EC).

Results: Twenty-five athletes were referred for further investigation (17 murmurs, 6 abnormal electrocardiographs, 1 displaced apex, and 1 possible case of Marfan syndrome). EC confirmed 3 structural and 22 physiological murmurs. The SP flagged 5 individuals with possible underlying structural pathology; 2 of these murmurs were confirmed as structural in nature. Fourteen murmurs were referred by CAA; 3 of these were confirmed as structural in origin by EC. One such murmur was not detected by the SP, however, and detected by CAA. The sensitivity of CAA was 100% compared with 66.7% shown by the SP, while specificity was 50% and 66.7%, respectively.

Conclusion: CAA shows potential to be a feasible adjunct for improving the identification of structural murmurs in the athlete population. Over-referral by CAA for EC requires further investigation and possible refinements to the current algorithm. Further studies are needed to determine the true sensitivity, specificity, and cost efficacy of the device among the athletic population.

Clinical Relevance: CAA may be a useful cardiac screening adjunct during the PHE of athletes, particularly as it may guide appropriate referral of suspected structural murmurs for further investigation.

Keywords: computer-assisted cardiac auscultation; cardiac murmur; periodic health assessment; athletes

From the [†]Institute for Sports and Exercise Medicine, Division of Orthopedics, Faculty of Medicine and Health Sciences, Stellenbosch University, Stellenbosch, South Africa,

[‡]Campus Health Service, Stellenbosch University, Stellenbosch, South Africa, and [§]IOC Research Centre South Africa, Cape Town, South Africa

*Address correspondence to Pierre L. Viviers, MBChB, MMedSc, MSc (Sports Med), FACSM, Campus Health Service, Stellenbosch University, Private Bag X1, Matieland, Stellenbosch, 7602, South Africa (email: plviviers@sun.ac.za).

The following author declared potential conflicts of interest: Wayne Derman, MBChB, BSc(Med)(Hon), PhD, FFIMS, is a paid consultant for Ossur South Africa, has provided expert testimony for various medico-legal issues, and received payment for lectures including service on speaker's bureaus.

DOI: 10.1177/1941738117695221

© 2017 The Author(s)

Identification of structural heart disease in athletes remains a significant challenge for clinicians. Indeed, the presence of cardiac murmurs identified during the periodic health evaluation (PHE) often leaves the clinician with the difficult task of distinguishing between functional and pathologic variants in athletic populations.^{3,7} In low-resourced settings, cardiac auscultation is in most instances the only and most cost-effective method to identify murmurs¹¹; however, limitations of the standard stethoscope have resulted in declining reliance on auscultation findings.^{3,16} Availability and access to expensive advanced technological devices, time constraints of a thorough cardiac auscultation, and the decline of adequately skilled physicians are major contributing factors that limit the role of traditional auscultation. In the African (and other low-resourced) environments where an “open hall or station approach” to the PHE is often followed, the environment might be noisy, which makes routine auscultation difficult. Furthermore, mid-level-trained health care workers often assist with the PHE, which adds to the complexity of identifying athletes at risk.^{5,6} Within this background, advancement in auscultation technology, specifically computer-assisted auscultation (CAA), has emerged as an objective diagnostic support tool in the evaluation of murmurs in nonathlete populations.^{3,5,16}

Computerized auscultation incorporates the techniques of phonocardiography, sonvelography, and spectrocardiography to assist in evaluation of auditory information detected by physicians through a stethoscope and incorporates visual patterns to support clinical decision-making when murmurs occur.² However, in the past decade, rapid technological advances have been made not only with respect to electronic stethoscopes but also in the associated computer analysis of data.¹³ Indeed, in recent studies, CAA has shown promise as an objective diagnostic support tool in assessments conducted in the pediatric setting. In a study involving board-certified physicians, CAA increased the sensitivity to detect structural murmurs from 82.4% to 90.0% ($P < 0.001$) while the specificity of correctly identifying benign cases rose from 74.9% to 88.8% ($P < 0.001$).¹⁴ Furthermore, a study conducted in a realistic clinical environment within South Africa using novel signal processing techniques and an artificial neural network achieved a sensitivity of 91% and a specificity of 94% to detect structural systolic murmurs.¹¹

Despite these promising results, to the best of our knowledge, the use of CAA in the athletic population as part of PHE has not been studied previously. Accordingly, we conducted a feasibility study among collegiate athletes in a realistic clinical environment applicable to the local setting using CAA as part of the routine PHE protocol. The aim of this study was to determine the feasibility of inclusion of CAA into the setting and whether this technique has the ability to detect the presence of structural murmurs in conjunction with a sports physician (SP) in the screening of a collegiate athlete cohort.

METHODS

This study was approved by the local health research ethics committee (HREC # N14/02/12), and all participants were

required to provide informed consent in accordance with the Declaration of Helsinki. A cohort of collegiate athletes from different sporting codes was assessed for cardiac murmurs during a routine PHE at a single university. Athletes completed the American Heart Association (AHA) cardiac history questionnaire⁹ and underwent a comprehensive physical examination with an SP, and if indicated, a 12-lead electrocardiogram (ECG) was conducted (Model PCR 100; Welch Allyn). In addition, a side room CAA investigation was performed by a non-clinically trained research technician.

An ECG was triggered by any findings that may have raised suspicion of underlying cardiovascular abnormalities and/or disease. This involved a thorough history taking by the SP to confirm any positive answers identified in the AHA cardiac history questionnaire as well as the identification of any abnormal clinical findings such as a deviation in the pulse rate and rhythm from normal parameters or the presence of a heart murmur.

All murmurs detected by either the SP or CAA were referred for echocardiography (EC) conducted by an independent cardiologist. In addition, other specific clinical indications such as stigmata of Marfan syndrome, a displaced apex (in the presence of suggestive underlying cardiovascular disease), or abnormal ECG findings (ie, a pattern indicative of possible pathology according to the Seattle Criteria)⁴ were referred for further assessment to the cardiologist.

Based on the EC results, which served as the gold standard, the number of true positives, true negatives, false positives, and false negatives were analyzed for both diagnostic utilities. Importantly, the SP was blinded to all CAA findings throughout the entire study so as not to influence their clinical decision-making. Murmurs detected by the SP were classified as being structural or physiological in nature, while the CAA algorithm was preprogrammed to make a class 1 or class 3 referral decision (developed using a nonathletic cohort). According to the AHA and American College of Cardiology, class 1 recommendations for EC indicate at least a moderate likelihood that a murmur reflects structural heart disease while a class 3 recommendation specifies that EC is not required for patients who have a grade 2 or softer midsystolic murmur identified as being innocent by an experienced clinician.¹

Screening took place within a designated assessment room housed within the university's campus health service facility. Only those athletes who were older than 18 years were eligible for the study. Exclusion criteria included athletes who had any history of previous cardiac surgery or those who were unable to provide informed consent.

Data collected during this study consisted of demographic information (participant name, date of birth, and type of sporting participation), basic anthropometry (weight, height, and body mass index), selected CAA parameters (presence or absence of a structural murmur, its location, measures of heart rate, RR interval, average systole length, and average diastole length), and information obtained from the SP-driven medical consultation (AHA cardiac history questionnaire and a comprehensive systemic examination). Furthermore, EC findings and cardiologist recommendations were recorded.

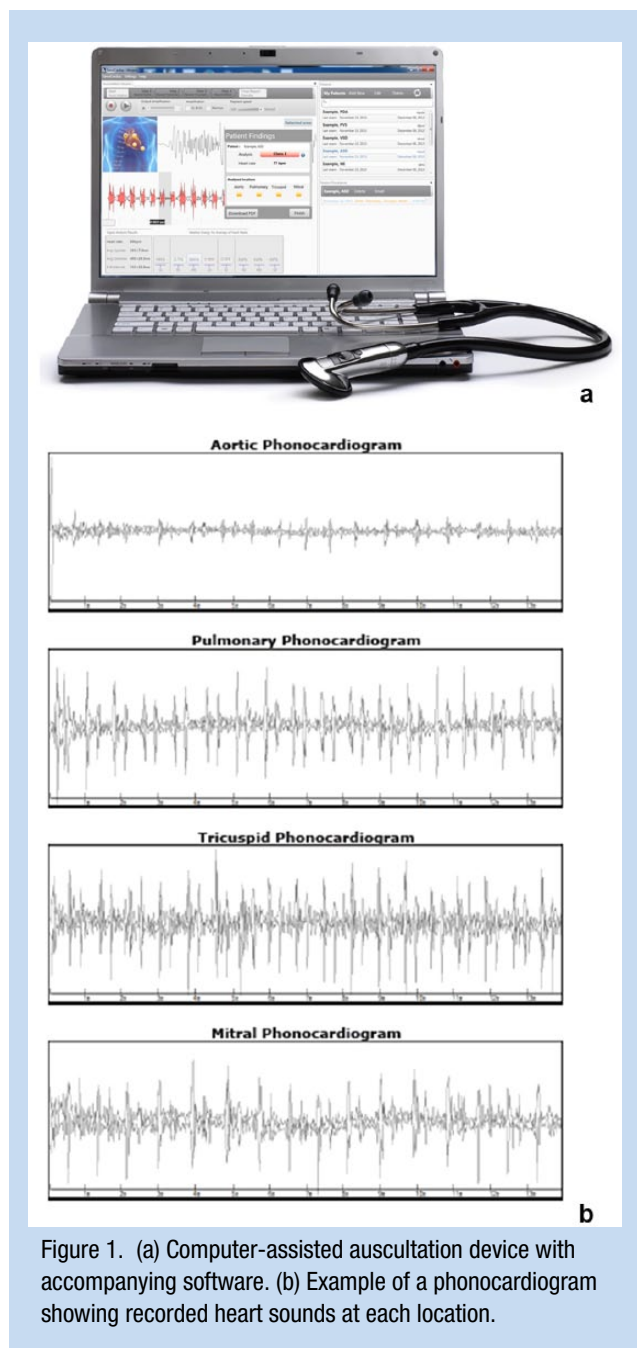


Figure 1. (a) Computer-assisted auscultation device with accompanying software. (b) Example of a phonocardiogram showing recorded heart sounds at each location.

Details of the CAA Assessment

A SensiCardiac system (Diacoustic Medical Devices) was used to record a 20-second interval of heart sounds at each of the 4 main auscultation locations (the aortic, pulmonary, tricuspid, and apex areas of the heart) in both the supine and sitting positions (16-bit data, sampled at 4 Hz). The system makes use of a software application and a Littmann electronic stethoscope (model 3200; 3M Health Care) to capture and analyze heart sound recordings (stored as a .wav file on a computer) and transferred via Bluetooth technology to either a laptop or via an app to a smartphone (Figure 1). The relative energy distribution within a recorded

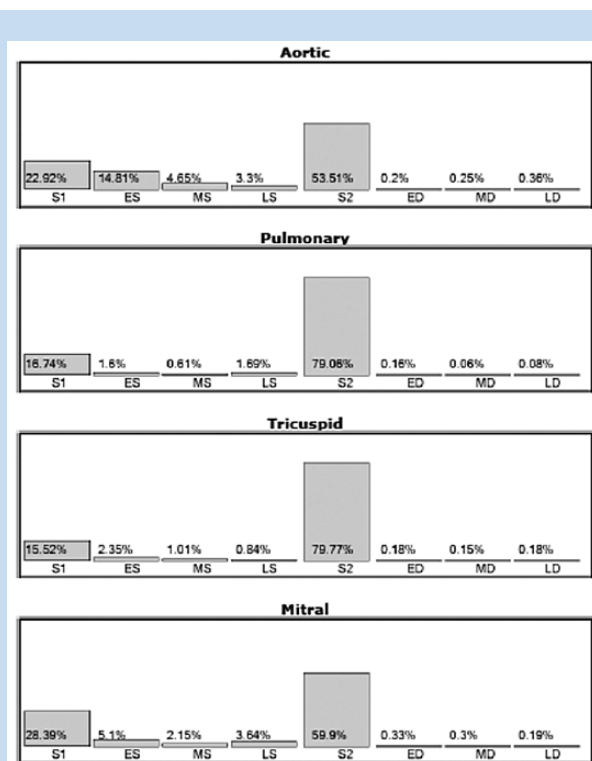


Figure 2. An example of the average midrange energy distribution in the recorded heart beats of a participant with a structural murmur identified by computer-assisted auscultation. The total relative amount of energy for the heart beats equals 100%, while the energy within each component is indicated as a fraction of the whole. In order: S1, first heart sound pulse; ES, early systolic; MS, mid-systolic; LS, late systolic; S2, second heart sound pulse; ED, early diastolic; MD, mid-diastolic; LD, late diastolic.

heartbeat (Figure 2) provides valuable information about the murmur timing (ie, early, mid-, or late systole or diastole).

Statistical Analysis

Data entry and analysis were carried out using Statistica 12 software (StatSoft Inc). Categorical data were expressed in frequency and percentages, employing a chi-square test as appropriate, while continuous data were expressed using means and SDs. In addition, sensitivity and specificity were determined for each diagnostic utility.

RESULTS

In total, 131 athletes were screened (104 men, 28 women; mean age, 20 ± 2 years). Participant characteristics and responses to the AHA cardiac history questionnaire are represented in Tables 1 and 2, respectively.

The SP suspected 5 structural murmurs compared with 14 deemed as having structural pathology by the CAA software. A total of 25 referrals were made to a cardiologist, 17 of which were

Table 1. Participant characteristics

	Mean	SD
Age, y	20.48	1.97
Weight, kg	76.71	14.26
Height, cm	176.72	9.40
Body mass index, kg/m ²	24.39	2.92
Systolic blood pressure, mm Hg	119.55	10.29
Diastolic blood pressure, mm Hg	71.67	8.21

Table 2. Summary of athlete responses to the American Heart Association cardiac history questionnaire⁹

Question	Positive Responses, n (%)	Negative Responses, n (%)
1. Have you ever passed out during exercise?	9 (7)	122 (93)
2. Do you ever experience discomfort, pain, or pressure in your chest while exercising?	11 (8)	120 (92)
3. Does your heart race or skip beats during exercise?	10 (8)	121 (92)
4. Has a doctor ever said you have high blood pressure?	2 (2)	129 (98)
5. Has a doctor ever said you have a heart murmur?	4 (3)	127 (97)
6. Has a doctor ever said you have high cholesterol?	2 (2)	129 (98)
7. Has a doctor ever said you have a heart infection?	0 (0)	131 (100)
8. Has a doctor ever ordered a test for your heart?	5 (4)	126 (96)
9. Are there any deaths in your family for no apparent reason?	2 (2)	129 (98)
10. Does anyone in your family have a heart problem?	15 (11)	116 (88)
11. Has any family member died of sudden death or heart problems before the age of 50?	8 (6)	123 (94)
12. Does anyone in your family have Marfan syndrome?	1 (1)	130 (99)

suspected structural murmurs and 8 for clinical reasons of concern. Three of the suspected structural murmurs were detected solely by the SP, 12 by CAA, and 2 by both CAA and the SP. Overall EC revealed 3 instances of a structural murmur (1 patent foramen ovale, 1 ventricular septal defect, and 1 trival pulmonary stenosis) and 22 cases of a physiological murmur. These 3 cases of confirmed structural pathology did not require any further intervention and, according to Bethesda guidelines, did not exclude these collegiate athletes from sporting activities.¹⁰

The sensitivity of CAA was 100% compared with 66.7% shown by the SP, while specificity was 50% and 66.7% for the measured techniques, respectively. It is important to note that the interpretation of these numbers is limited as there was no EC

performed on the entire group and thus, the true pathology in the total cohort is unknown.

DISCUSSION

The present study sought to determine whether CAA could be a feasible adjunct in the clinical decision-making of cardiology referrals by an SP in the PHE of an athletic population. Previous studies have shown the beneficial use of CAA in screening of pediatric populations with both a high sensitivity and specificity for murmur detection.^{8,11,12} Contrary, our investigation revealed a high sensitivity but a reduction in the specificity of CAA compared with SP. This difference may be attributable to the

fact that previous studies were done within a pediatric setting, using a software algorithm specifically developed for this population. Therefore, in the present study, exercise-induced cardiovascular adaptations may have presented interpretational difficulties for the current software algorithm.

The first important finding of this study indicates that while the inclusion of CAA in the PHE of athletes may be feasible, its current software algorithm requires further refinement for use in this setting. Of the 14 athletes that CAA deemed to have structural murmurs, only 3 cases were confirmed by EC while the remaining murmurs were all shown to be physiological in nature. It is of interest that CAA managed to detect an additional structural murmur, confirmed to originate from a patent foramen ovale, which was not identified by the SP. In comparison, the SP detected 5 suspected structural murmurs, of which 2 were confirmed by EC. The inability of CAA to distinguish between physiological and structural murmurs resulted in a number of unnecessary referrals in this study. Retraining of the current CAA algorithm (which was developed for the nonathlete pediatric population) may address this particular finding.

A major limitation of this study is that EC was not performed on all participants. Therefore, the true sensitivity, specificity, as well as positive and negative predictive values could not be determined.

It is therefore clear that further studies of this technology together with EC, in the setting of the adult athlete, are warranted. It might be tempting to speculate that if CAA is proven to be appropriately sensitive and specific in this setting, its application may prove to be especially valuable in low-resourced environments with particular relevance to sub-Saharan Africa, where currently, major shortages exist within the health care workforce.¹⁵ Reports have shown that a lack of sport physicians and other highly trained health care practitioners may result in scenarios where skill sharing or shifting of tasks normally performed by specialists to mid-level and community health workers occurs.⁶ Consequently, the need for reliable, objective, and cost-effective support tools is particularly relevant within the context of the African PHE where traditional auscultation is the first-line diagnostic practice of choice. Moreover, auscultation, which is considered to be a lost art, relies heavily on a user's proficiency, clinical consistency, and level of experience, resulting in failure to detect structural murmurs or overreferral for costly specialist investigations for benign physiological murmurs, and advances in technology might in the future assist with improving training and appropriate referral. Thus, the above points make a strong case for further studies of this technology in these settings.

Additional barriers to effective PHE in developing countries include limited access to specialist health care due to poor socioeconomic status as well as no mandatory screening protocols. On those occasions where athletes are seen for any ailments or periodic health check-ups, this will more than likely be done by a general practitioner or community nurse. Consequently, there is still a significant need to introduce a simple and affordable cardiac screening program in underresourced areas.

CONCLUSION

The findings of this study suggest that while CAA may feasibly be included in the PHE, further refinements are necessary to the existing software algorithm. Cardiac auscultation remains a useful investigative tool in the PHE; indeed, in this study, 3 cases of structural abnormality were identified, with 1 case missed by the SP but identified by CAA. Therefore, CAA may have a place as a supportive tool to assist sports medicine practitioners with their clinical referral decision process, especially in resource-limited areas. A unique strength of this study was the use of novel technology in a realistic African clinical environment. However, future studies using larger athlete cohorts evaluating the sensitivity, specificity, and cost efficacy of this method are needed.

ACKNOWLEDGMENT

The authors thank Mr Thys Cronje for the use of the photos as well for technical support with the CAA device.

REFERENCES

1. Bonow RO, Carabello BA, Chatterjee K, et al. 2008 focused update incorporated into the ACC/AHA 2006 guidelines for the management of patients with valvular heart disease. *J Am Coll Cardiol*. 2008;52:e1-e142.
2. Cathers I. Neural network assisted cardiac auscultation. *Artif Intell Med*. 1995;7:53-66.
3. Chizner MA. Cardiac auscultation: rediscovering the lost art. *Curr Probl Cardiol*. 2008;33:326-408.
4. Corrado D, Pelliccia A, Heidbuchel H, et al. Recommendations for interpretation of 12-lead electrocardiogram in the athlete. *Eur Heart J*. 2010;31:243-259.
5. De Vos JP, Blanckenberg MM. Automated pediatric cardiac auscultation. *IEEE Trans Biomed Eng*. 2007;54:244-252.
6. Fulton BD, Scheffler RM, Sparkes SP, Auh EY, Vujicic M, Soucat A. Health workforce skill mix and task shifting in low income countries: a review of recent evidence. *Hum Resour Health*. 2011;9:1.
7. Kovacs R, Baggish AL. Cardiovascular adaptation in athletes. *Trends Cardiovasc Med*. 2016;26:46-52.
8. Leung TS, White PR, Collis WB, Brown E, Salmon AP. Analysing pediatric heart murmurs with discriminant analysis. *Conf Proc IEEE Eng Med Biol Soc*. 1998;3:1628-1631.
9. Maron BJ, Thompson PD, Puffer JC, et al. Cardiovascular preparticipation screening of competitive athletes. A statement for health professionals from the Sudden Death Committee (Clinical Cardiology) and Congenital Cardiac Defects Committee (Cardiovascular Disease in the Young), American Heart Association. *Circulation*. 1996;94:850-856.
10. Maron BJ, Zipes DP. 36th Bethesda Conference: eligibility recommendations for competitive athletes with cardiovascular abnormalities. *J Am Coll Cardiol*. 2005;45:2-64.
11. Pretorius E, Cronje ML, Strydom O. Development of a pediatric cardiac computer aided auscultation decision support system. *Conf Proc IEEE Eng Med Biol Soc*. 2010;2010:6078-6082.
12. Sepehri AA, Hancq J, Dutoit T, Gharehbaghi A, Kocharian A, Kiani A. Computerized screening of children congenital heart diseases. *Comput Methods Programs in Biomed*. 2008;92:186-192.
13. Tavel ME. Cardiac auscultation: a glorious past—and it does have a future! *Circulation*. 2006;113:1255-1259.
14. Watrous RL, Thompson WR, Ackerman SJ. The impact of computer-assisted auscultation on physician referrals of asymptomatic patients with heart murmurs. *Clin Cardiol*. 2008;83:79-83.
15. World Health Organization. The world health report: 2006: working together for health. <http://www.who.int/iris/handle/10665/43432>. Accessed March 8, 2016.
16. Zühlke L, Myer L, Mayosi BM. The promise of computer-assisted auscultation in screening for structural heart disease and clinical teaching. *Cardiovasc J Afr*. 2012;23:405-408.